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The expansion and decline of charophyte communities in lakes within the Sejny Lake District (north-eastern Poland) and changes in water chemistry

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Abstract

Over the last 25 years, considerable changes have been observed in the littoral vegetation of 11 lakes within the Sejny Lake District. In eight lakes (Dowcień, Jurkowo, Kunis, Miałkie, Pilwie, Płaskie, Wiłkokuk, Zelwa) where *Chara* species dominated, their communities declined or disappeared completely. In four of these lakes (Dowcień, Jurkowo, Kunis and Miałkie), charophytes were replaced by communities of the class *Potametea* (mainly *Nupharo-Nymphaeetum albae* and *Ceratophylletum demersi*). In three other lakes (Pilwie, Płaskie and Wiłkokuk), the area covered by charophyte communities decreased. In Lake Zelwa, *Charetum rudis* and *Charetum jubatae* disappeared while *Charetum tomentosae* and *Charetum fragilis* expanded. A total area of charophyte communities remained approximately the same. A considerable increase in the water total hardness and PO_4^{3-} concentration was noted in each of the eight lakes. In most of them increased levels of dissolved organic matter (measured as COD-$KMnO_4$) and pH were detected as well. However, the increase in the PO_4^{3-} concentration was smaller in Lakes Wiłkokuk and Zelwa in which only slight changes in the vegetation were observed. In the above two lakes, the concentration of dissolved organic matter decreased and low water colour values are now noted. In three lakes (Długie, Dmitrowo and Gajlik), the charophyte communities tended to expand under the condition of moderate or high (Lake Długie) PO_4^{3-} concentration, while dissolved organic matter concentrations were low. These lakes are also characterized by low values of colour. Charophyte communities may persist in lakes for a long period of time even when there is a moderate increase in PO_4^{3-} concentration until the colour of water distinctly increases ($>20\,\mathrm{mg\,Pt\,L^{-1}}$).

Keywords: *Charetea*; *Potametea*; Submerged vegetation; Water chemistry; Long-term study

Introduction

In the years 1975–1978, phytosociological studies were conducted on the vegetation of 66 lakes within the Sejny Lake District (Tomaszewicz & Kłosowski 1985). The results of this study encouraged us to repeat the investigations and assess the scale of the changes in vegetation after about 25 years in these lakes. Therefore, in 2002, the authors of this study resumed their investigations in the lakes within the Sejny Lake District. The research in the years 2002–2003 covered all the 66 lakes investigated 25 years ago. This paper reports on the vegetation changes within all the lakes, where charophyte communities (class *Charetea* Fukarek, 1961) covered area greater than 10% of littoral

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during any of the two research periods. There were eight lakes where charophyte communities dominated over large areas in the years 1975–1978 and three more lakes, where the area of charophyte communities was significant (over 15% of littoral) in the years 2002–2003. Altogether the paper handles with 11 lakes.

Charophytes are generally recognized as one of the first colonizers in water bodies (Lambert-Servien, Clemenceau, Gabory, Douillard, & Haury 2002; Spence 1982; Wade 1990). They are also regarded as indicators of clear-water ecosystems (Krause 1981) and are replaced by communities of the class *Potametea* R.Tx. et Preisg. 1942 as a result of progressive eutrophication (Auderset Joye, Castella, & Lachavanne 2002; Blindow 1992; Forsberg 1965; Lang 1981; Ozimek & Kowalczewski 1984; Wiegleb 1978). In the present publication, we analyse long-term vegetation changes in the lakes with charophyte communities within the Sejny Lake District. The objectives of this study were to determine the scale of the changes in aquatic vegetation over the 25-year period, establish whether and to what extent these changes were associated with changes in water quality and to indicate which hydrochemical parameters were responsible for the expansion, persistence and decline of charophyte communities.

Material and methods

Eleven lakes were surveyed in the present study (Table 1). The initial field observations made on the vegetation of the lakes in 2002 were followed by investigations carried out in 2003 during the vegetative season. The same methods as 25 years ago were applied. Sigma relevés (Géhu 1977) were used to estimate the area occupied by the particular littoral plant communities. By "littoral" the area of shallow water which is colonized or suited to colonization by submerged macrophytes and reed swamp communities is meant. The vegetation of each lake was established on the basis of a relevé (analogous to phytosociological relevés), in which the abundance of each community in the lake littoral was determined according to a modified Braun-Blanquet (1951) scale in which + = several patches, mean coverage 1%; 1 = 1–10% coverage, mean 5%; 2 = 10–25% coverage, mean 17.5%; 3 = 25–50% coverage, mean 37.5%; 4 = 50–75% coverage, mean 62.5%; 5 = 75–100% coverage, mean 87.5%. The strip transect method was used for estimating the area occupied by the particular communities (sigma relevés). Since only the relationships between the occurrence of charophyte and aquatic vascular plant communities were analysed, reed swamp communities were not considered in the present work. The differences in the proportion of area occupied

Table 1. Some characteristics of the lakes under study

Lake	Area (ha)	Max. depth (m)	Geographic coordinates	pH		Total hardness (mval L^{-1})		PO_4^{3-} (mg L^{-1})		COD-$KMnO_4$ (mg O_2 L^{-1})		Colour (mg Pt L^{-1})
				1978	2003	1978	2003	1978	2003	1978	2003	2003
Dowcień	18.5	n.d.	54°02′N 23°24′E	6.5	8.8	2.42±0.16	3.20±0.20	0.060±0.020	0.110±0.030	9.80±0.80	12.77±0.65	23±4
Jurkowo	23.5	n.d.	54°03′N 23°14′E	7.9	7.9	3.90±0.20	4.30±0.20	0.100±0.020	0.204±0.102	9.45±0.70	14.59±0.79	29±5
Kunis	42.5	4.0	54°02′N 23°26′E	7.6	8.5	3.70±0.10	4.03±0.42	0.070±0.010	0.120±0.020	6.63±0.36	6.50±0.41	17±2
Miałkie	27.5	n.d.	54°02′N 23°13′E	7.7	7.8	3.40±0.20	4.33±0.15	0.175±0.033	0.243±0.096	10.13±1.00	13.56±0.79	28±5
Płaskie	26.3	5.8	54°08′N 23°16′E	7.5	8.0	2.00±0.10	2.67±0.21	0.074±0.030	0.153±0.021	10.37±0.59	16.30±1.87	27±5
Pilwie	12.2	3.7	54°05′N 23°28′E	7.6	8.1	2.93±0.21	3.47±0.45	0.016±0.010	0.105±0.016	8.25±0.75	10.56±1.99	22±7
Wiłkokuk	39.1	12.2	54°00′N 23°24′E	7.5	8.6	3.25±0.25	3.60±0.26	0.060±0.060	0.071±0.019	6.80±0.42	6.50±0.66	12±2
Zelwa	103.7	12.3	54°01′N 23°25′E	6.9	8.7	3.00±0.30	3.40±0.17	0.060±0.020	0.094±0.040	10.01±0.89	6.17±0.69	9±3
Długie	102.4	48.0	54°06′N 23°10′E		8.4		2.07±0.31		0.114±0.053		7.29±0.65	4±1
Dmitrowo	61.2	42.0	54°05′N 23°16′E		8.7		2.40±0.10		0.091±0.033		7.61±0.43	6±2
Gajlik	16.0	6.9	54°04′N 23°27′E		8.2		4.07±0.06		0.086±0.052		7.45±0.69	13±2

n.d. – no data.

by the particular plant communities were presented in percent.

Surface water samples were collected three times (May, July, September) in each lake. Each sample consisted of three subsamples collected within littoral of a lake investigated and mixed together. The mean values were calculated from these samples for each lake. For the purpose of this study, the same properties as 25 years ago were determined: pH using pH-meter N-517, total hardness using Warthy-Pfeifer sodium mixture, chemical oxygen demand (COD) as consumption of $KMnO_4$ in acid medium, total phosphates spectrophotometrically by molybdate method, water colour according to the platinum–cobalt scale. Data on vegetation and water chemistry which were obtained 25 years ago were compared with the present results. The paired *t*-test was applied to determine significant differences of the water properties of the lakes 2003 and 1978. Changes in the charophyte communities and water properties were displayed as bar charts. The Spearman rank correlation test was used to assess the relations between charophyte occurrence and the water parameters analysed in the study. In the case of Lakes Długie, Dmitrowo and Gajlik, for which no earlier hydrochemical data were available, the current data have been presented. All the investigated lakes were compared with respect to their present colour (in the year 2003).

Results

Vegetation changes in the lakes investigated

Compared to 1978, charophytes had until 2003 disappeared completely from four of the lakes investigated (Dowcień – *Charetum tomentosae* (Sauer, 1937) Corillion, 1957; Jurkowo – *Charetum rudis* Dąmbska, 1966, *Charetum contrariae* Corillion, 1957, *Charetum fragilis* Fijałkowski, 1960; Kunis – *Charetum tomentosae*, *Charetum contrariae*, *Nitellopsidetum obtusae* (Sauer, 1937) Dąmbska, 1961; Miałkie: *Charetum tomentosae*, *Charetum rudis*, *Charetum fragilis*, *Charetum jubatae* Krausch, 1964, *Nitellopsidetum obtusae* – Fig. 1). At the same time, an expansion of aquatic vascular plant communities from the class *Potametea*, particularly *Ceratophylletum demersi* Hild, 1956 and *Nupharo-Nymphaeetum albae* Tomaszewicz, 1977, was observed in three lakes (Lake Jurkowo, Kunis, Miałkie).

A somewhat different scenario was observed in Lakes Płaskie, Pilwie, Wiłkokuk and Zelwa. Some of the charophyte communities disappeared completely from these lakes, others experienced a decline, whereas the area of some of the other charophyte phytocoenoses increased in Lake Zelwa (Fig. 1). In Lake Płaskie, the area occupied by the phytocoenoses of *Charetum tomentosae* decreased from 66% to 11%, whereas the *Charetum fragilis* communities disappeared completely. The area occupied by *Charetum rudis* and *Nitellopsidetum obtusae* in the lake remained the same. The phytocoenoses of *Charetum fragilis* retreated from Lake Pilwie, whereas the area covered by *Charetum tomentosae* decreased to approximately 5%. In Lake Wiłkokuk, the area of *Charetum tomentosae* declined from 60% to 40%. The patches of *Charetum jubatae*, which had covered only a small area of the lake, disappeared, whereas those of *Charetum rudis*, *Charetum fragilis* and *Charetum contrariae* were able to persist. The phytocoenoses of *Charetum rudis* and *Charetum jubatae* disappeared from Lake Zelwa, and among the phytocoenoses which persisted in the lake (*Charetum contrariae, Nitellopsidetum obtusae*, *Charetum tomentosae*, *Charetum fragilis*), the area of the latter two increased to several percent. In the lakes mentioned above, a marked expansion of *Potametea* communities was not observed in these places where the charophyte phytocoenoses had disappeared.

A completely different scenario was observed in Lakes Długie, Dmitrowo and Gajlik (Fig. 1), in which the expansion of charophyte communities is now taking place. Among two types of communities (*Charetum tomentosae*, *Nitellopsidetum obtusae*) that were recorded in Lake Długie 25 years ago, only the patches of *Charetum tomentosae* increased their area, and now cover about 40% of the littoral area. In Lake Długie, *Charetum contrariae* appeared in 2003. Charophyte communities were absent in Lake Dmitrowo 25 years ago. During 2003, 79% of the littoral area was occupied by *Charetum tomentosae* and *Nitellopsidetum obtusae* phytocoenoses. In addition, the phytocoenoses of *Charetum asperae* Corillion 1957 and small patches of *Potametea* vegetation have been found. In Lake Gajlik where the charophyte communities were not encountered 25 years ago, the *Nitellopsidetum obtusae* covered about 17–18% of the littoral area during 2003.

Changes in water properties and vegetation

In the four lakes where charophyte communities had disappeared (Dowcień, Jurkowo, Kunis, Miałkie), total hardness and concentration of PO_4^{3-} increased significantly between 1978 and 2003 (Tables 1 and 2). In Lakes Płaskie, Pilwie, Zelwa and Wiłkokuk where the charophyte communities declined, only the increase in water hardness was significant (Table 3). In the latter group of lakes, an increase in PO_4^{3-} concentrations was indicated as well, and in the case of the two lake groups, the pH of water was higher although the increase was not statistically significant. In five lakes (Dowcień, Jurkowo, Miałkie, Płaskie, Pilwie), the values of COD-$KMnO_4$ which indicates the amount of dissolved organic matter

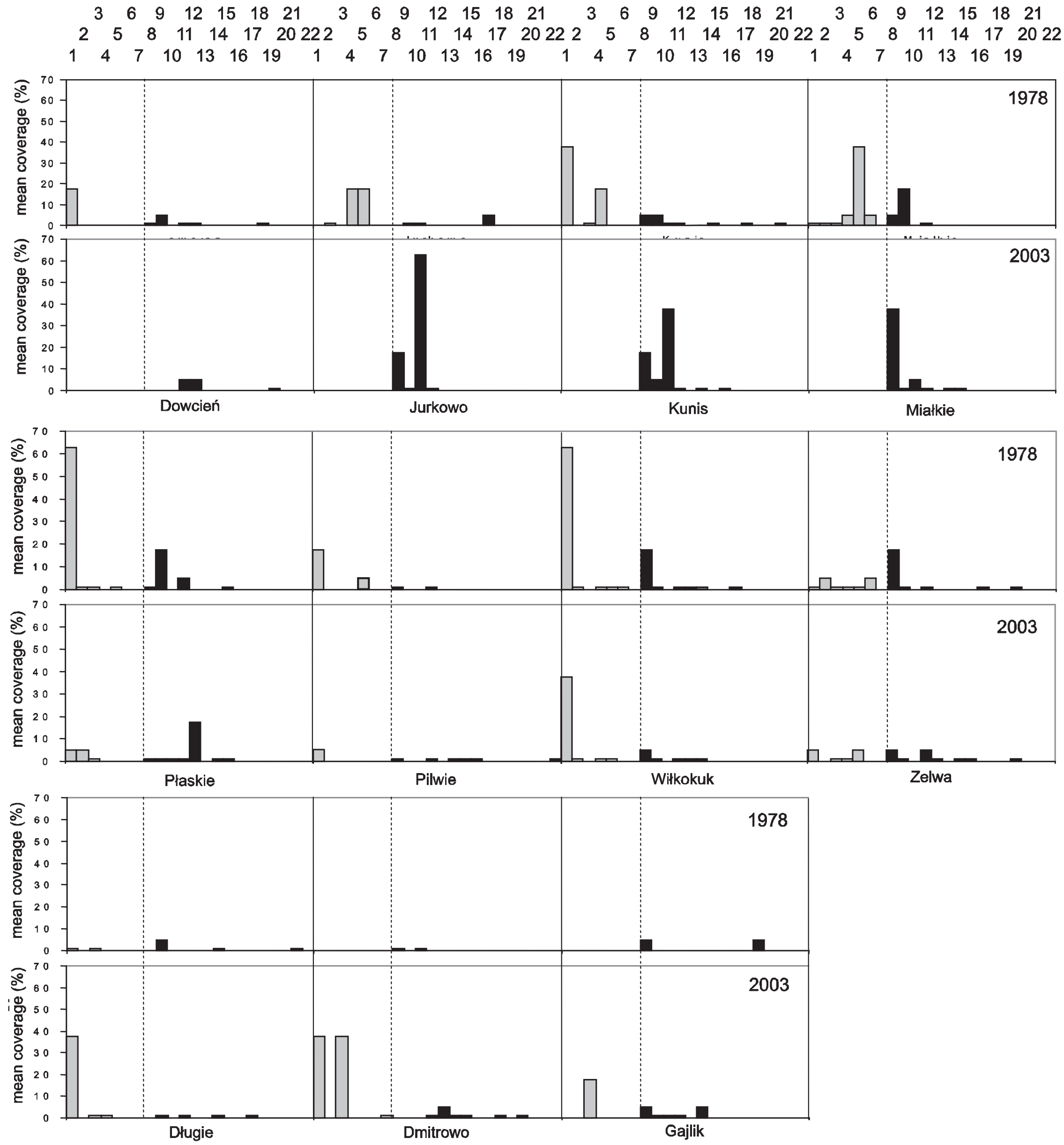

Fig. 1. Vegetation coverage of the lakes investigated in 1978 and 2003. Grey bars – charophyte communities (*Charetea*); black bars – aquatic vascular plant communities (*Potametea*). 1 – *Charetum tomentosae*, 2 – *Charetum rudis*, 3 – *Nitellopsidetum obtusae*, 4 – *Charetum contrariae*, 5 – *Charetum fragilis*, 6 – *Charetum jubatae*, 7 – *Charetum asperae*, 8 – *Nupharo-Nymphaeetum albae*, 9 – *Hydrocharitetum morsus-ranae*, 10 – *Ceratophylletum demersi*, 11 – *Potametum natantis*, 12 – *Myriophylletum spicati*, 13 – *Myriophylletum verticillati*, 14 – *Potametum lucentis*, 15 – *Hydrilletum verticillatae*, 16 – *Elodeetum canadensis*, 17 – *Ranunculetum circinati*, 18 – *Potametum compressi*, 19 – *Potametum perfoliati*, 20 – *Potametum friesii*, 21 – *Polygonetum natantis*, 22 – *Najadetum marinae*.

Table 2. Statistical significance of differences (paired *t*-test; $p<0.05$) between the water properties analysed in Lakes Dowcień, Jurkowo, Kunis, Miałkie after 25 years

	pH	Total hardness	COD-$KMnO_4$	PO_4^{3-}
p	0.2183	**0.0247**	0.0895	**0.0146**

in water increased as well. COD-$KMnO_4$ did not change in Lake Kunis. In Lakes Wiłkokuk and Zelwa, the values of COD-$KMnO_4$ even decreased. Therefore, the average increase in COD-$KMnO_4$ values after 25 years is not significant (Tables 2 and 3). Fig. 2 shows the relationship between the changes in the charophyte abundance and the changes in water chemical

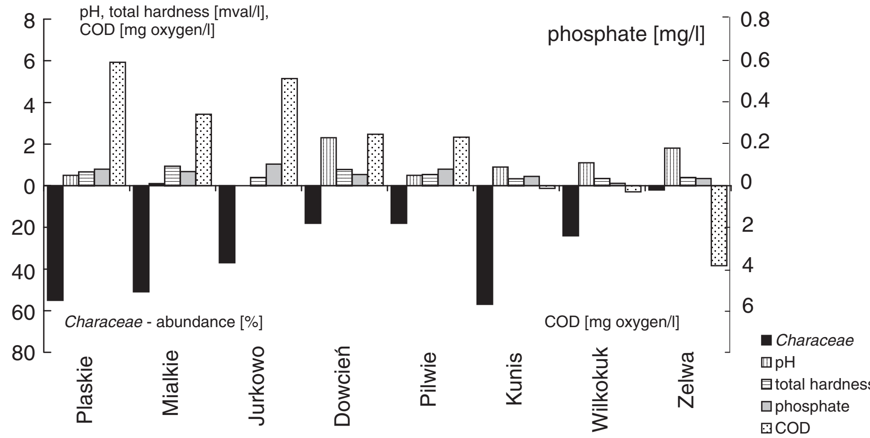

Fig. 2. Changes in pH, COD-$KMnO_4$ total hardness, PO_4^{3-} and charophyte abundance in the eight lakes investigated in the 1978 and 2003. The bars indicate differences between the values obtained in 2003 and 1978. Bars in the upper half – increase in values; bars in the lower half – decrease in values.

Table 3. Statistical significance of differences (paired *t*-test; $p<0.05$) between the water properties analysed in Lakes Płaskie, Pilwie, Wiłkokuk, Zelwa after 25 years

	pH	Total hardness	COD-$KMnO_4$	PO_4^{3-}
p	0.0511	**0.0065**	0.6536	0.0634

parameters analysed in present study. The disappearance or decline of charophytes is significantly correlated with an increase in pH and PO_4^{3-} concentration (Table 4) The smallest changes in charophyte vegetation occurred in Lake Zelwa, where the COD-$KMnO_4$ values did not increase, but they actually decreased.

In the lakes in which the charophyte communities expanded (Długie, Dmitrowo, Gajlik), the waters are alkaline and the present PO_4^{3-} concentration is not lower than in the lakes where charophyte communities declined. The total hardness of water varies, i.e. it is low in the lakes with more luxuriant growth of charophyte species (Długie, Dmitrowo) and reaches higher values in Lake Gajlik where the abundance of *Chara* vegetation is lower (Table 1, Fig. 1).

Lakes experiencing the strongest expansion of charophyte communities, Długie and Dmitrowo, are characterized by the lowest values of water colour (Table 1). The colour of the water of these lakes was most similar to that of Lakes Wiłkokuk and Zelwa in which the changes in charophyte vegetation were much smaller than in other lakes. Fig. 3 and Table 5 show that there is a significant positive correlation between lake colour and phosphate concentrations whereas a negative correlation is found between these two parameters and charophyte occurence. Charophytes are abundant in waters where the colour values are low ($<15\,mg\,Pt\,L^{-1}$) even when the PO_4^{3-} concentrations increase and exceed $0.1\,mg\,L^{-1}$.

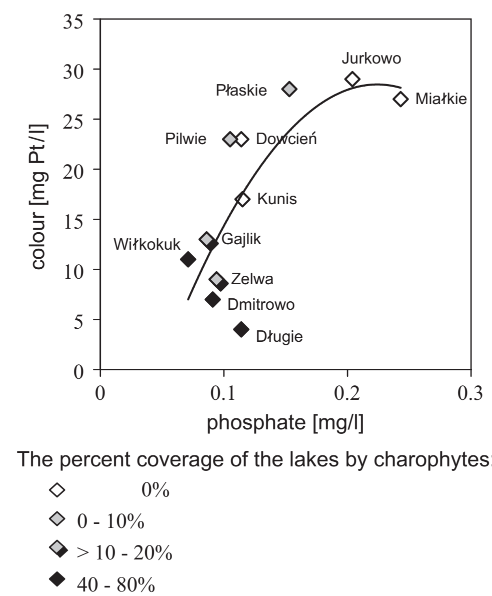

Fig. 3. Relationships between phosphate concentrations, lake colour and charophyte abundance in 2003.

Discussion

A decline of *Chara* species and their communities has often been observed in various types of water bodies in Europe and other parts of the world (Auderset Joye, Castella, & Lachavanne 2002) This is mainly due to the progressive eutrophication (Blindow 1992; Lang 1981; Melzer, Faber, & Kohler 1977; Ozimek & Kowalczewski 1984; Van den Berg 1999). Until recently the increasing ($>20\,\mu g\,L^{-1}$) phosphorus concentration (Forsberg 1964, 1965; Hough & Putt 1988) was regarded as the main factor limiting the growth and expansion of

Table 4. Spearman rank correlation between water properties investigated and charophyte abundance

	pH	Total hardness	COD-$KMnO_4$	PO_4^{3-}
Charophytes	**−0.5338 (0.0332)**	−0.3632 (0.1667)	−0.4144 (0.1105)	**−0.5944 (0.0152)**

R and *p*-values are given (*p*-values in brackets). Data obtained from eight lakes in 1978 and 2003.

Table 5. Spearman rank correlation between lake colour, phosphate concentrations and charophyte abundance

	PO_4^{3-}	Colour	Charophytes
Charophytes	−0.7717 **(0.0054)**	−0.7717 **(0.0054)**	
Colour	0.6918 **(0.0184)**		
PO_4^{3-}			

R and *p*-values are given (*p*-values in brackets). Data obtained from 11 lakes in 2003.

charophytes. However, further studies indicated that various *Chara* species can occur in waters with high phosphorus (Blindow 1988, 1992; Bornette, Gurlesquin, & Henry 1996; Kufel & Ozimek 1994) and nitrogen (Simons & Nat 1996) concentrations. Table 1 shows as well, that the increase in the phosphorus concentrations is separately of no direct importance. Although the phosphates concentration increased considerably (more than two-fold in Lakes Jurkowo, Płaskie, Pilwie) in the lakes from which the charophyte communities had completely disappeared or declined, it hardly be expected that it is the dominant or the only factor limiting the growth of charophytes and their communities. The P-concentrations in the three lakes in which charophytes expand are not low and particularly in Lake Długie its values are higher than the present values obtained for some of the lakes from which the charophytes disappeared or declined (Table 1). The indirect effects of eutrophication, which among others lead to the massive algal blooms and reduced water clarity (Van den Berg 1999) could play a more significant role. The increase in PO_4^{3-} concentrations is significant when it leads to an increase in water colour. In lakes containing rich charophyte vegetation, the colour values are low ($<15\,\mathrm{mg\,Pt\,L^{-1}}$) even when phosphate concentrations reach or slightly exceed $0.1\,\mathrm{mg\,L^{-1}}$ (Fig. 3). Charophytes begin to decline once the colour values exceed $15–20\,\mathrm{mg\,Pt\,L^{-1}}$, which is correlated with an increase in phosphate concentrations ($>0.1\,\mathrm{mg\,L^{-1}}$). The relationship between lake colour, phosphate concentrations and charophyte occurrence indicated in this study could confirm the concept of alternative stable states (Scheffer 1998).

It is generally recognized that most charophytes and their communities prefer hard alkaline waters, rich in calcium (Kufel & Kufel 2002). The pH and the total hardness of the waters increased in most of the lakes investigated, due, among others, to more intensive erosion of soils rich in calcium from the agricultural fields that have been abandoned. Such conditions should thus favour the development of charophytes. However, in many lakes, the increase in pH and hardness of water is accompanied by an increase in nutrient concentrations and strong decline in water transparency. Under these conditions, charophytes start to decline. The charophyte communities may persist in waters for a long period of time under the condition of moderate increase of water fertility and turbidity due to the enhanced sedimentation of particles inside *Chara* meadows and consequently restoration of clear water (Van den Berg 1999). The data regarding the conditions existing in Lakes Wiłkokuk, Zelwa, Długie, Dmitrowo and Gajlik support this hypothesis.

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